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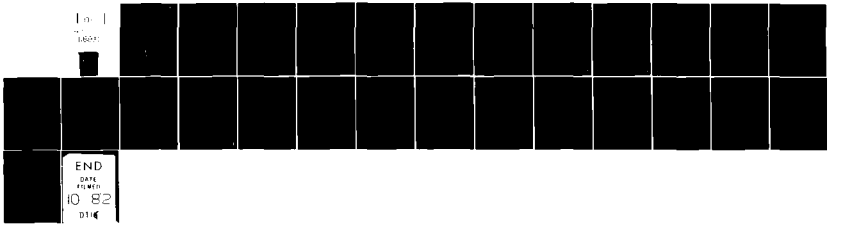

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A BRIEF HISTORY OF PHYSICS IN CHINA

by

Dai Nian Zao

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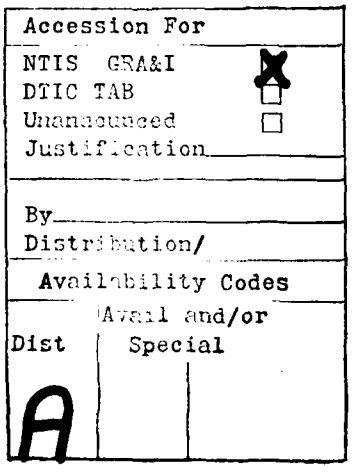

A BRIEF HISTORY OF PHYSICS IN CHINA

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This paper will present a major profile of the history of development of ancient physics in China, with coverage up to 1900. Physics history in this century in China will be followed up later. Comments and corrections on this paper are welcomed.

DEVELOPMENTAL SITUATIONS AND CHARACTERISTICS OF PHYSICS IN CHINA

As we all know, generally speaking,—scientific theories occur later than the practice of production and living, just as the manufacturing of pragmatic tools and utensils was born before the theories of mechanics, and languages and music were born earlier than the theories of sound. Strictly speaking, in ancient history the word 'physics' was not used, because there were no such things as concepts, theories, definitions and laws in physics that systematically make up science. Nevertheless, ancient people did have much guesswork, observations, calculations and experiments on physical phenomena. Though scattered, they are however the pioneer developments of modern physics, if judged from the viewpoint of history and development. Ancient people's speculative explanation of physical phenomena is widely regarded as the origin of modern scientific thinking. Thus 'ancient physics' is conventionally used to represent the dull period of the development of physics.

China is one of the oldest civilized countries in the world, and physics has a long history in China.

During the period of primitive societies, in working practice people sowed the seed of physics when they had learned to use fire and make stoneware. The Bronze Age emerged when society entered the slavery ages of Hsia, Shang and Western Chou dynasties. Handicraft industry in Western Chou was very well developed, with great varieties and detailed subdivisions and 'all kinds of skilled laborers' who mastered specialized skills. Technical development created an environment for the accumulation of physical knowledge, laying a foundation for summarizing physical theories.

The Spring and Autumn Period and the Period of the Warring States saw the transition from the slavery system to the feudal system in our country. The transition from the Bronze Age to the Ironware Period was completed. With metallurgy and the application of iron tools, the development of agriculture and irrigation, and the prosperity of town building, and the spur of wars and merging of the states, ancient physics in China began its period of formation marked by the Book of Mo Zi and "On Examining Crafts."

During the 1200 years starting from the Chin, Han and through the Three Kingdoms, Tsin, Southern and Northern Dynasties to the Sui, Tang and Five Dynasties, ancient physics in China experienced greater development: 1. the construction of many complicated machines on a large scale such as the south-pointing cart, the water driven armillary, distance-registering cart and so on; 2. the invention of many small tools such as incense tray, light-transparent mirror and the Han Wash; 3. documentation of a large amount of experience or speculative theories about physics as evidenced in "On Balancing," "Ten Thousands Techniques From Huai Nan" and "Documentation On the Miscellanies."

The Sung and Yuan dynasties were the prosperous time of ancient physics development in China. During this period, in addition to the inventions and construction of large scale machines and production tools, five books relevant to physics were written. They are "Diary alongside a Stream of Dream," "Summaries on Armament," "Summaries on New Patterns and Phenomena," "Models and Guide of Constructions" and "New Book on Phenomena." Powder, the compass and movable type printing - the three great inventions that are so

well known in the world - are the products of this period. The discovery of the magnetic dip, experiments on resonant paper puppets, large scale optical experiments, the invention of the hydrometer and the demonstration of surface tension, are all a great contribution from this period.

Physics in China during the Ming and Ching dynasties found itself in a relatively backward stage when compared to the West's modern physics. On the other hand, due to the occasional buddings of capitalism in our country and the development of production technology, there were some individual physical discoveries that were of particular note. Furthermore the knowl dge of modern physics began to propagate in our country with the arrival of western evangelists.

The period from 1910 to 1949 can be termed the drafting stage of physics in China. Our country's modern physics had its preliminary development from 1949 to the present time.

There are some characteristics pertaining to the history of physics in China. First, its development is continuous. It has been through its origin, development, prosperity and decay, and it is born again by merging into the main stream of world physi in this century. It is unlike the physics in ancient Greece and Rome that died with the death of ancient Greece and Rome, nor does it resemble physics in Arabia that only achieved in a single area such as optics. Second, when compared to any contemporary nation in the world, the content of physics in ancient China was extremely rich, having full development in heat, mechanics, sound, light, electricity/magnetism and philosophical theories of material composition. Ancient China's various technical inventions and the documentation and knowledge about various physical phenomena provided tremendous material for studying the historical rhythm of the development of physics. There are those countless observations, experiments and sparks of thought that constitute the forerunners of the birth of modern physics. Third, the atomic theory in ancient physics in China was weak; instead, the thought of material 'essence or air' was popular. Because such 'air' was everywhere and bountiful, it was thought to be the medium in all nature's long distance actions such as

electricity/magnetism, resonance, and tides and ebbs. There was neither the concept of long distance action nor the idea of 'nature abhors a vacuum' in the thought of the ancient Chinese.

THE EVOLUTION OF THE WORD 'WULI'[1]

The emergence of the word 'wuli' in Chinese is not that late. The following was written in the book "Huai Nan Zi" which was completed around 200 B. C., 'Whereas speculum mirrors get fire from the sun, magnets attract iron and sunflowers face the sun, these are the things which cannot be reasoned even by the intelligent. Therefore what the eye sees and what the ear hears can't tell wuli, nor can right or wrong be judged by the heart and the mind.' The 'wuli' in the text denoted generally the reason for all matter, and it is not what the physics of nowadays means. "Wuli Theories" was written by Yang Chuan in the Tsin Dynasty and "Wuli Knowledge" was written by Fang Yi Zhi (1611-1671) between Ming and Ching. Though they were termed 'wuli,' however what was included were various departments of natural science and also certain branches of humanistic science.

Scholars in the Sung dynasty such as the metaphysicist Ju Si (1130-1200) often used the words 'the utter li of wu' or the word 'wuli'; however it was a popular term used in their idealist philosophy meaning the pre-experimental 'li' controlling the physical 'wu,' 'li' being a concrete matter prior to the existence of materials. Such a concept is just the opposite of the real meaning of physics.

In late Ching, physics was included in the so called 'study of ge wu.' Such a study at that time covered all natural sciences except mathematics, astronomy, medicine and agriculture. In the translation of modern western physics, various areas of physics and chemistry were given the same translation 'ge wu,' with mechanics being translated as 'the study of weight.' 'Ge wu' is the short form of an ancient Chinese term 'ge wu zi

[1] Translator's note: 'Wuli' is 'physics' in Chinese.

zhi'[1] hence the study of ge wu was occasionally called 'the study of ge zi.' In 1901 there were eight divisions (equivalent to today's departments) set up in the capital's university. They were classical literature and canon, medicine, the study of ge zi, and so one. In his "Scream," Lu Xin wrote: 'I learned from this university that there are such things as ge zi, mathematics, geography, history, painting and physical education.' Nevertheless the term 'ge wu zi zhi' originated from the chapter of advanced learning in the "Book of Rites": 'Knowing resides at the research into the nature of things. Knowledge arrives after the nature of things has been investigated.'

During the transition from Ming to Ching, knowledge of modern western natural science began to reach China. In "Xi Xue Fan" written by the priest Jules Aleni (1582-1649, Italian, came to China in 1610), physics was phonetically translated as 'fei xi ka.' It is not until 1900 when a Japanese named Fujita Tohachi[2] translated into Chinese from a book "Physics" by Meshmari Teizo[2], the translation being fine tuned and rearranged, and the book being printed by the Jiang Nan Manufactory that our country ever had the first physics book which possessed the content and system of modern physics.

FROM ANCIENT TIMES TO WESTERN CHOU (770 B. C.)

At a time as remote as 500,000 years ago, the Peking ape man had made sharpened tools and scraping tools by striking or filing stones. Probably man was inspired by the piercing pain inflicted by nature's sharp objects. In a period five to six thousands years ago, the splendid Yan Shao civilization and Long Shan civilization emerged, and the legendary Shen Nong Shi, Wang Di, Yao and Xin were the several large tribes during this period of primitive communes. The invention and construction of vehicles and boats demonstrated

[1]Translator's note: This means 'knowledge is derived from research into the nature of things.'

[2]Translator's note: Phonetic transliteration only.

that man began to utilize nature's power as well as human power. There was great progress in pottery, jade, stone, bone, wood utensils and textiles, and bronze probably emerged during the Long Shan civilization. Arrows and bows were important inventions at an early time in this period. According to a classical document, people then 'hollowed wood to make canoes, sharpened wood to make oars,' 'broke wood to make pestles, dug ground to make mprtars,' 'strung wood to make bows, sharpened sticks to make arrows.'[1] The bud of knowledge of mechanics was thus beginning to be nourished.

Pottery jars for fetching water were unearthed at the archaeological site of the Yan Shao civilization at Half Hill Village in Xian. The shape of such jars was: pointed at the bottom, large at the waist, small at the mouth. The two handles for attaching a rope are located just below the waist. Due to its peculiar shape the jar would sit upright or tilted depending on the amount of water in it. Placed on water, the jar would tilt when it is empty; it would turn upright when half full; and turned upside down when filled with more water. A 'tilting vessel' in the Western Chou period which tilts when empty, is upright when half filled and bottom up when full [2] was probably the development of this pointed bottom jar.

During the periods of Sia Shang and Western Chou, the construction of transportation tools such as various complicated carts and vessels, the invention and application of a time-measuring 'leaking pot', the utilization of a trading-necessity scale, lever and water bucket working up and down a well by means of a lever, all provided a pre-condition for the accumulation and summary of the knowledge of mechanics.

Primitive man first mastered one of nature's powers by utilizing and controlling fire. The invention of drilling wood for fire is a great event in the history of physics. In the production of heating pottery and melting copper ore, man gradually mastered heat and was able to judge temperature. The "Book of Poems" and the "Rites of Chou" both record the fact that people at this period began to store and use ice.

Ever since primitive times, the concept of beauty at least prompted women to look at their reflections on water and to groom themselves. In the Sia and Shang periods there were such ancient reflecting devices as 'washers' which were pottery pans for holding water. Bronze mirrors emerged in the In-Shang period. All of these contributed to the material grounds for the birth of optics. According to "On Examining Crafts" and the "Rites of Chou" there existed in the Western Chou period a speculum mirror (concave mirror) used in making fire. The use of a fire signal was also an invention during this period.

Musical instruments such as the single sonorous stone, pottery bell, and fife existed in very ancient times. There were bronze bells, leather drums and chimes during the Sia and Shang periods. The people of Shang had had the concept of absolute high pitch, and the chromatic scale thus emerged. In Western Chou, the "Book of Poems" documented 29 musical instruments - wind instruments like the pipe, syrinx, oboe and string instruments like the guitar, spinet, etc., in addition to the majority of instrument precursors. In early Chou, twelve tones and seven majors emerged.

The most ancient hypothesis on material composition was recorded in the "Book of Shang." Contemporaries reckoned that all matter was made up of the so called 'Five Essences' - metal, wood, water, fire, and earth. The different qualities of these five fundamental materials were also discussed. It was said that people of In-Shang divided nature into eight domains - sky, earth, thunder, fire, wind, ocean, mountain and water. Treating sky and earth as the basics, sky being Yang and earth being Yin - the people proposed the earliest concept of Yin-Yang. Such a pair of opposites as Yin-Yang was the essential physical motivation in the theory of air developed later in history. "Doctrine of Yin Yang and Five Essences' which combined Yin-Yang and the Five Essences thus explained all the matter in the universe and their movements.

THE SPRING AND AUTUMN WARRING STATES PERIOD (770 B. C. - 221 B. C.)

The Spring and Autumn Period can be regarded as the formative period of ancient physics if the earlier period is called the budding period of ancient physics. No Zi was a contemporary philosopher and physicist. The first name of Mo Zi (approximately early 500 B. C. - 400 B. C.) is Ze and he was a citizen of the Lu State. The Mo's founded by Mo Zi himself and his students was the scholastic branch that achieved the most in p' 'sics during the Spring and Autumn Period. There are two parts to his ' ok of Mo" - 'doctrine' and 'doctrine comments.' The 'doctrine' is prob Mo Ze's own work whereas 'doctrine comments' are the explanations by his ents or subsequent followers of Mo on the 'doctrines'. "Book of Mo" docu knowledge in the areas of mechanics, sound, light and the hypothesis of material composition.

In the "Book of Mo," force was defined as the 'cause of movement in objects.' Analysis was performed on the lever, pulley and inclined planes. In the research of the balance principle on the lever, not only was the factor of force and weight considered, but also the factor of the distance between two ends and the fulcrum. The balance concept of reaction and physical weight was developed and the balance principle of buoyant objects was discussed. In the area of mechanics, time and spece were correctly defined in the "Book of Mo". Topics such as sliding, pivoting and rolling, and the relationship of movement, time and space were addressed. The "Book of Mo" also suggested the concept of the indivisible 'end' of materials. The Mo's discovered the resonant effect of pottery wares that were buried in the ground. Nevertheless the Mo's greatest achievement was in optics. In the "Book of Mo", optics problems were recorded and discussed in sequence in eight phrases: the reason for formation of a shadow; the relationship of ray and shadow; experiment on the straight movement of light; light's reflectory character; size of a shadow determined by the relative position of object to light source; reflected image of plane mirror. These eight phrases were a faithful recording of Mo's precise observation on optical experiments. The sequence of recording meets the requirement of modern geometric optics. This is a rare and relatively complete work on optics in the history of ancient civilization in the world.

"On Examining Crafts" is a work by the people of Chi at the end of the Spring and Autumn Period. It is a collection of standards on handicraft techniques in ancient China. It discussed the contemporary major branches of handicraft. Included in the discussion of scientific principles were knowledge of mechanics, sound and heat. The book is a vivid manifest on the application of Chinese physical knowledge of handicraft technology.

In "On Examining Crafts", the examination method of the symmetry of wheels and arrows was discussed. (Placed on water, the state of buoyancy of various parts was observed.) It pointed out the examination technique for leather quality by exerting forces on the leather and observing the change in shape. The book rendered the earliest account of the moment of initia: "When the movement of the horse is exhausted, the vehicle still advanced for a distance'. It gave an excellent description of an inclined plane, through practical experience, as follows: For a hackery going uphill, the bull might be strangled to death if the shaft was not lowered; making a cart go uphill took an effort twice the weight as the cart; on a hackery going downhill, at least the belt behind the bull had to be pulled if the back of the hackery was not pulled [3].

In the chapter entitled 'Arrows' in "On Examining Crafts" the relationship between the construction of an arrow and its trajectory was analyzed in detail as follows. There had to be a definite ratio among the head, stick and feather so that an arrow could maintain a certain trajectory in a gusty wind. The arrow would not go straight if these three elements were not in proportion. The arrow would dive if the head was too light; would fly upward if the back was too light; would rotate if the middle part was too light; would tilt upward if the middle part was too heavy; would go slow with too many feathers and would fail to reach the target if there were too few feathers.

"On Examining Crafts" discussed in detail the manufacture of bells and their sounds. The proportions of the alloy were initially set at 'six parts copper and one part tin', and then the discussion was carried out in six paragraphs. First, the various parts of a bell and their location were defined. Second, the size of various parts of a bell was established.

Third, the effect of thickness, shape of the mouth and the ear length on the sounding of a bell. Fourth, the proportion of the wall thickness was established. Fifth, the size of a bell and the sound effect of a bell in relation to its size and length were addressed. Sixth, the proportion of the bell wall determined by a given tune. There were 254 words in the entire article, with distinctive sequence and tight logic. It is the first paper in the world that dealt with the technique of bell making, and it was almost 1500 years earlier than the comparable paper from Europe. In addition, this book also contained sound technology about drums and the single sonorous stone.

There is quite a quantity of documentation on heat technology. It was written as follows in the Chapter of Li Xi: 'The gas appearance in melting copper and tin is: After the cloudy black gas there will be yellowish white gas; after the yellowish white gas there will be greenish white gas; green gas follows after the expiration of the greenish white gas. It is at this moment that casting can be performed'. For the process of smelting and casting, since there are impurities such as carbon and sodium, and different elements have different vaporization points, the color of these vaporized elements can be used as a standard indication of temperature. Given a heated substance it appears dark red (approx. 550°C), and as the temperature is raised, it becomes orange, then yellow, and appears white at about 1000°C. In the process of heating pottery and metals, the ancient Chinese mastered the knowledge of telling temperature by the colors at various stages. And even nowadays the pottery and metal smelting workers in the vast rural area use such an ancient method to determine the stages of smelting without relying on thermometers.

In the chapter 'Di Su' in "Guang Zi" written at the end of the Spring and Autumn Period, "Gua Gu Zi" written during the Warring States Period and in "Spring Autumn of Li Xi" completed at the end of the Warring States Period, natural magnets and the phenomenon of attracting iron were documented, in addition to the most ancient south-pointing device 'Si Nan'.

The Chapter 'Di Yuan' in "Guang Zi" documented the loss-or-gain-by-one-third method of fixed note tuning - using a string length of a certain note, its various notes can be subsequently derived by either multiplying two-thirds (losing one-third) or four-thirds (gaining one-third) on the standard string length. This is the earliest example of ancient physics in which a mathematical formula is employed to summarize a physical phenomenon. The chapter 'Miscellanies' in "Zhang Zi" completed from 400 B. C. to 300 B. C. was the earliest to record the resonant phenomenon of strings.

The philosophical theory on material composition grew during this period. In addition to Mo's discussion, the chapter 'Water and Earth' in "Guang Zi" speculated that water was the origin of all matter (inorganic domain) and all living things (organic domain). The famous conclusion by Wei Si (approx. 370 B. C. - 310 B. C.) is: 'A thing is termed the largest when there is no other thing larger; a thing is termed the minimum unity when there is no other thing smaller'. His concept of minimum unity declared that there exists a limit in the division of matter. However, Gong Xun-Long (approx. 320 B. C. - 250 B. C.) proposed: 'There will never be an end or exhaustion in dividing an arm-length stick in half and its half in half and this process can be continued indefinitely'. His statement indicated that matter could be divided indefinitely. Sung Yan and Yin Wen in 400 B. C. held the hypothesis that all matter in the universe is unified in 'air'. Thereafter the thought of the atomic theory basically stopped and the doctrine of essence and air enjoyed full growth.

FROM CHIN TO FIVE DYNASTIES (221 B. C. - 960 A. D.)

This is the development period of ancient physics in our country.

HEAT

As early as the Han dynasty, our nation discovered and utilized high temperature fuel - coal, petroleum, natural gas. Du Shi in the Eastern Han invented a blasting mechanism which was convenient to metallurgy in raising and controlling temperature.

It was from weather changes that man first observed the changing states of matter. Wang Chong of the Eastern Han (29-97) gave a detailed discussion in "On Balancing" of the stages of 'Rain is from land and not from the sky' and 'vapored clouds come from hills and mountains, and become rain when they fall and disperse'. He pointed out 'being an omen of rain, clouds and fog become dew in summer, frost in winter, become rain when weather is warm, become snow when weather is cold' [4]. Living examples of the three phase variation of ice, water, and vapor were documented in manu ancient books. Especially in "The Book of Liu Zi" by Liu Zhou of Northern Chi in which the phenomenon 'ice is born from water but is colder than water' was pointed out. Of course it was impossible for ancient folk to discover the temperature at which both ice and water co-exist.

Beginning from the Han dynasty, using the principle of hot rising air, people made lanterns which drifted up in the air as military signals. There were some who imaginatively made egg shells fly off the ground for three to five feet in gusty wind by heating the inside of the egg shells. It was recorded in the Han dynasty "Miscellaneous Techniques from Huai Nan" that if a water filled copper pot is heated and its mouth sealed tight and it is rapidly dumped into a well, a thundering noise would result. It was probably due to the phenomenon of interior cracking when a heated object is suddenly cooled off. It was recorded in "National Documentation of Hua Yang" that Li Bing (dates of birth and death unknown) broke obstructive gigantic rocks using the principle of 'expansion under heat and shrinkage when subject to cold' during the embankment project of Du Jiang around 250 B. C. It was a practice for the minority ethnic group dwelling in the western region during the Tang dynasty to lower room temperature in hot summer time by introducing water onto their roofs.

Chang Hua (232 - 300) of the Tsin dynasty wrote in the "Book of Natural Science": 'In the heating of oil, as the vapor has come to an end and there is neither smoke nor boiling again, then the oil is still cold and can be stirred with the hands. There will be flame when water is added, and it will be extinguished when dispersion comes to an end. Such a method seldom fails'. This experiment not only indicated the different boiling points of oil and water, but also revealed the phenomenon of stages of boiling oil.

According to a record in chapter ten of "Miscellanies of Chou Yang" by Duan Cheng-Shi in the Tang dynasty, when Liu Bon, the founding father of the Han dynasty, marched into Han Yang Palace in 206 B. C., there was such a lantern in the palace: 'seven feet five inches high, with a hornless dragon holding the lantern. When the lantern is lit its scales will tremble, twinkling as the stars'. Both this kind of lantern and the regular running horse lanterns which appeared in later days created an air current with heated air to make tiny objects such as paper horses rotate. It is the ancestor of the modern steam engine.

Ancient peoples determined high and low temperature from what their bodies felt. They ventured into and also discussed some theories on heat. Wang Chong said: 'The water in a big pot will not get hot even after a day when heated by a single flame, a kitchen will not get cold even after a night when cooled with a cubic foot of ice. Why? Because small bodies have little effect on huge things' [25]. 'Coolness is felt in the vicinity of water, and warmth is felt when near a fire. The feeling of cold or warmth diminishes as distance increases. Why? There is a difference in distance as far as air is concerned'.

What is heat? It was written in "Guan Yin Zi", completed during the Southern and Northern Dynasties: 'There are variations of temperature on things such as tiles and rocks. Hot when heated, cold when submerged in water, warm when a breath is expelled onto them, and cool when blown on. This is because ambient matter can flow, whereas tiles and rocks lack such a flow'. From this point of view, the flow of 'ambient matter' causes the tiles and rocks to change temperature to hot, cold, sarm and cool. It was reckoned in heat physics in the 18th century that the heat propagation from a high temperature object to lower temperature object contributes to the heat substance intrinsic to the objects. Such a concept of heat substance can be traced all the way back to ancient times. Liu Yu of Northern Chi said: 'Metals contain water and wood conceals fire. That is the reason why water emerges when metal is being heated and fire erupts when wood is being drilled'[7]. Explaining that friction and rubbing cause fire from the standpoint of the 'five essences', he thought that the element 'fire' is one

of the qualities intrinsic to wood. The theory of burning elements of the 18th century conceded that heating objects by burning was due to a 'fire element' or 'burning element' entering the objects; however, the theory of a burning element could not explain heat caused by rubbing, and it was on the problem of friction generating heat that this doctrine encountered much trouble and hence collapsed.

MECHANICS

Machines and their applications had tremendous development. Beginning in the Han dynasty various simple machines such as the lever, lever operated water buckets, and pulleys were used in combination, and the gear was invented. Chang Heng (78 - 139) constructed the armillary. He married the images of the heavens with the time-indicating 'leaking-pot' by means of a system of gears. Dripping water drove the gears which in turn drove the celestial globe in revolutions. In 132, Chang Heng invented the world's first seismograph which was used to determine the quale's origin. The plow, the three-legged-rake used for sowing and a water pestle ten times as efficient as the ordinary pestle were all inventions in the Han dynasty. Bi Fong constructed the first 'rotating cart' i.e. dragon bone water wheel and invented a siphon called the 'thirsty bird'. Du Yu of the Tsin dynasty invented the continuous pestle. Chu Chung-Chih in the Southern Dynasty constructed a water driven pestle and water driven grinder. Chiu Liang of Northern Wei made a water driven pulverizer. Both Chang Heng, Chu Chung-Chih and Ma Jin during the Three Kingdoms Period respectively made the south-pointing cart which was a direction pointing device. The distance registering cart and the armillary were constructed by many others at different times. In 725, Jen Yi-Hung and Liang Lin-Chuan of the Tang dynasty made a water driven armillary which was capable of indicating the revolution of the sun and the moon, and of registering time.

In the Han dynasty there was a skilled craftsman named Din Wuen from Chang An who constructed an 'incense tray' - an instrument in which 'the body of the tray was always level with wheels spinning on the periphery'[8]. That was the world's first gyroscope. There was a metal pan called 'wash' or 'Han wash'. Inside the pan there were four dragons or four fish and hence it was referred to as a 'dragon wash' or 'fish wash'. Water inside the pan

would show various fascinating patterns when the pan's two handles were rubbed by two hands. This is the oldest Chladni picture whose author E. L. Chladni (1756 - 1827) made vibrating nodes visible with grains of fine sand sprinkled on the vibrating plate, whereas the Han Wash used water. During the Western Han, a scale-like humidity apparatus with equal arm lengths was invented. Equal weights of charcoal and feathers (iron or dirt) were placed at the ends. As the charcoal absorbed moisture and hence the weight changed, the variation in atmospheric humidity could be determined.

Various illustrated books on apparatus and equipment were destined to be made. They were: "Essays on Various Tools"; "Archery" which dealt with the construction of bows and arrows plus the problems of trajectory; "Playing Soccer" which summarized the principles of center of gravity and equilibrium in acrobatics; "Techniques in Weighing" and "Book of Weighing" by Chu Heng (approx. 5th - 6th century), son of Chu Chung-Chih; "Standard of Apparatus" by Xin Du-Fong of Northern Chi - 'Illustrated collection of various fascinating devices such as the armillary, tilting vessel, seismograph, bronze bird, time telling leaking-pot and so on'. It is a pity that those books that dealt with machinery manufacturing and mechanical principles were all lost.

Works by Wang Chong manifested the budding area of mechanics. He wrote: 'For carts traveling on land and for boats advancing on water, the motion is delayed and slow when the vessel is fully loaded while swift movement can be expected for empty vessels'. 'It is difficult for a heavily loaded vessel to' move quickly'[9]. This sentence indicated that, under a given external force, heavier objects move slower, their initial motion and acceleration is more difficult. There was much description in his works of force and motion.

During this period, there was a fairly good record of the general behavior of fluids. Specific weights of some substance were explored and actually examined. The fact that the flow speed of the leaking-pot varied with change in temperature was known. The production applications of siphons and water pumps aroused man's research on atmospheric pressure and vacuum phenomena.

It was written in "Guan Yin Zi" that: 'Water can be poured from a water filled bottle that has two small holes in it. Water fails to come out when of the small holes is sealed. This is because water will not lower when air does not rise. Water can be drawn from a well that is a thousand fathoms deep. Because water will not rise when air does not lower'. *Wang Bing of the* Tang dynasty wrote in the remarks of his "Questions": 'After an empty tube is filled with water and turned upside down with its mouth covered by a finger, the water will not leak out. Water fails to lower because there is no rising of the air. It is impossible to fill an empty bottle having a small mouth with fast running water because the water will not enter when air does not exit'.

In the 12th year of the Tang dynasty (724), Yi Hung (named Chang Sui, 638 - ?), Nan Gong-Sho and several others on their own went to eleven locations to measure latitudes and to measure the lengths of a cane's shadow. Nan Gong-Sho surveyed the distance in four locations in Honan province - Hua Xian, Kai Fong, Fu Gou and Shan Chai. In computing the relationship between difference in cane shadow lengths and the distance from southern to northern land, they once compared the latitude with the distance on land and consequently discovered that one degree in latitude is equivalent to 251.27 Tang Li (approx. 129.22 km) in south-north distance separation. Though this value was not accurate, nevertheless it was the world's first physical survey of the meridian.

Among the large quantity of works on materia medica, there was an abundance of description about the geometry of crystals such as minerals, metals etc. Specifically in 200 B. C. there had been an observation recorded of hexagonal snow flakes in "Poems of Han Ying" by Han Ying. Compared to an impromptu work "Hexagonal Snow" by J. Kepler (1571-1630) in 1611 which did not get completed, "Poems of Han Ying" was 1700 years older.

It is most interesting to note that in "The Woof of Spring and Autumn", a book of unknown author in Western Han - there were the oldest statements on the principle of relativity comparable with that by Galileo. 'The Earth is

in continuous motion without the knowledge of man. This is analogous to the fact that men sitting in a big boat in motion with the window shut are not aware of the boat's movement'[10]. There had been a lot of documents on the relativity of motion. Ge Hong (283 - 363) pointed out in "Pao Po Zi": 'The moon is said to be moving eastward when clouds are drifting in a westward direction'. The book "Guan Yin Zi" discussed the dispute of which was actually moving - the boat or the water. Chu Shi (300 A. D.) of the Tsin dynasty conceded that 'When traveling in a boat on water, it is the water that is moving and not the boat'[11].

SOUND

Wang Chong of the Eastern Han rendered a fantastic description of sound: 'How can a man sitting up on a stage and looking for ants detect their sound when he cannot even see their bodies? Why? Because when compared to man, ants are small in size and what sound they make cannot reach far. A foot long fish is swimming in water, and the area of the stirred waters is only a few feet. An object as large as a man is capable of causing vibration as far reaching as a hundred steps and it is all quiet and undisturbed a mile beyond. This is due to long separation. The way a man disturbs the air at a distance is the same as fish disturbing the water. The way the air responds is the same as water'[12]. The first sentence indicates that sound made by small ants, if there is any, can only be heard within a certain distance. This expressed the relationship between sound and propagation distance. The latter sentence, by using the example in which fish stirred water waves, further clarifies that this propagation distance is limited. It is finally pointed out that the way man's motion (including speaking of course) causes vibration in surrounding air to propagate to a distance is the same as the fish in water. Furthermore, the way 'air' vibrates is analogous of water waves. Wang Chong's using water waves as an analogy of sound waves was the world's first acquaintance with waves.

Musical instruments experienced tremendous development during this period. Royal musician Che Dao-Yuen (dates of birth and death unknown) of the early Da Zhong period (847 - 860) in the Tang dynasty was able to play

beautiful music from a set of bowls each of which was filled with a different amount of water. The Chinese were the first to invent such a method of controlling the vibrating frequency of a sound source by either adding or reducing the amount of water. Resonance of various musical instruments was documented in many ancient books. Chang Hua (232 - 300) of the Tsin dynasty and Tang's Chao Siao-Kuei (early 800 A. D.) even mastered the technique of eliminating resonances.

In the area of music, Jin Fan (77 B. C. - 37 B. C.) of the Han dynasty divided a major into 53 musical notes. Chian Le-Zi of the third century (dates of birth and death unknown), Shen Zhong of the sixth century (dates of birth and death unknown) divided a major into 360 musical notes. Sen Shu (? - 289) of the Tsin dynasty constructed twelve 'de's' (nowaday's flageolet) which were capable of giving precise tones. He was also the first to compute the adjusted value on the mouth of a tube. Ho Ching-Tien (370 - 447) of the Southers and Northern Dynasties performed a daring renovation in which he divided the length of the ancient tonic differential into twelve equal parts and then accumulated onto the twelve note 'de's, hence solving the length problem of returning from Xian and becoming Guan. He did not distribute the ancient tonic differential by frequency; however his thought is the forerunner of inventing twelve even tones.

LIGHT

The study of light during this period was characterized by the making of various mirrors. Concave speculum mirrors were popular in making fire. Focusing of the speculum mirror was initially investigated in the book "Huai Nan Zi". Besides the speculum mirrors, people also discovered many other objects capable of converging light. Gao Yiou of the Han dynasty in "Huai Nan Zi" listed a trimless metal glass capable of making fire. In the book "On Balance", Wang Chong listed two apparatus qualified to be speculum mirrors. 'Speculum mirrors get fire from the sky... Melt five kinds of rocks and mold into a shape and polish until shining. Fire will come when such a tool is turned facing the sun. This is the real way to start a fire. Fire

can also be made by reflecting the sun using shining weapons such as swords.' It was reckoned by people of latter days that such 'five kinds of rocks' might have been glass. Chang Hua did write that fire could also be started by using rounded ice cubes and transparent peals - a method of making fire with a convex lens.

As early as the beginning of the Han dynasty, man was aware of the combination of plane mirrors. People in Southern Tang wrote 'A mirror reflects an object as an image, and this image is reflected by another mirror and such a process is repeated until many images result'[13]. People during the Han dynasty implemented the oldest open periscope: 'Suspend a large mirror above, all the surroundings will be seen when a water filled basin is placed below it'[14]. Tan Shao (dates of birth and death unknown) of Southern Tang described four kinds of lenses in his "Book of Hua": 'Laymen usually possess four lenses: Kuei, Zu, Chi, and Yu. The image from Kuei is enlarged, the image from Zu is reduced, the image from Chi is upright and the image from Yu is upside down'. Kuei is a double concave diverging lens; Zu is a double convex converging lens; Chi is a plano-concave diverging lens and Yu is a plano-convex converging lens. Thus it is obvious that contemporaries had experimentally mastered the imaging of various lenses.

The 'light transparent mirror' was born in the Han dynasty. When a beam of light is cast onto the surface of a metal mirror, the design on the back is distinctively reflected onto a screen. Thus it was called the 'light transparent mirror' by ancient folk. Such a fantastic display had drawn attention at home and abroad. It was called the 'magic mirror' and 'mirror of unequal curving index' respectively in Japan and Western Europe. The manufacturing technique will be given in the following article.

Documentation and experiments on rainbows and chromatic dispersion are a great achievement in light for this period. Chai Yi of the Han dynasty described in his "Moon Essays" the formation condition of the rainbow: 'There are green and red colors on a rainbow which is always attached to dark clouds. Rainbows are visible when there is sun in the daytime. They are

invisible in the absence of clouds or bright light. Their positions are always the opposite of the sun; they would be seen in the east when the sun is in the west'. In "Remarks on the Book of Rites" Kong Wing-Da (574 - 648) wrote: 'When clouds are so thin that the sunlight can shine through, then a rainbow will form as the sun shines on rain drops'. In the mid 18th century, Chang Zhi-Ho (dates of birth and death unknown) of the Tang dynasty recorded a simple experiment on an artificial rainbow in the book "Xuan Zhen Zi": 'Something with the resemblance of a rainbow will form when water is sprayed from the mouth of a man whose back faces the sun', and these were called the 'Twist Halo'[15]. Furthermore, Ge Hong (283 - 363) of the Tsin dynasty recorded in chapter eleven in the book "Pao Po Zi" five kinds of mica which, when placed under the sun, revealed various colors. This is documentation on membrane interference. Chang Hua once recorded eight diffractions under the sun of peacock feathers and a certain worm native to southern Jiao Zhou. During the reign of Empress Wu in the Tang dynasty (684 - 705), Princess An Le had two dresses made of the feathers of many birds. 'When these dresses were viewed from the front, they exhibited a certain combination of colors that were different from those when viewed from the side. When the dresses were placed in the shadow, the colors appeared to be different from those when the dresses were placed under the sun'[16].

Chang Hong gave the correct explanation of moon light and the phenomenon of the lunar eclipse. He said: 'Moon light is born where the sun shines, and darkness is formed where the sunlight is blocked. Bright when it faces the sun, the brightness disappears when the moon is away from the sun. When there is sunlight and the light is not exact or matching, an eclipse of the moon is formed when sunlight is blocked by the earth'[17].

The chapter 'Tang Wen' in the "Book of Le Zi" recorded the interesting story of little children arguing about the sun. There were two kids arguing whether the sun was closer to the earth in the morning or at noon. Regarding such a complicated optical problem, Chu Shi (300 B. C.) of the Tsin dynasty conceded that it had something to do with man's visual illusion. And Jian Ji (second half of 4th century to 5th century) even suspected the effect of

'wandering air'. It is thought that such a 'wandering air' should be the absorption by the atmosphere and the phenomenon of extinction.

Slides or moview of an embryonic stage were born during this period. In 200 B. C. the wizard Chi Shao-Yiong (dates of birth and death unknown) once used slides to recreate the image of the deceased Madame Li for Emperor Wu of the Han dynasty who miserably missed the lady. According to chapter 97 in the "Book of Han": 'At night, candles were lit and the curtain was set... From a distance a lady having the same features as Madame Li was seen. She was returning to the bed to sit, and she was walking. However the emperor was even more longing and depressed as he was unable to have access to the image at a closer distance.' As a matter of fact, there might have been primitive slides as early as the Warring States Period. It was written in the book "Han Fei Zi" that someone painted intricate pictures on the inner membrane of a pea, and it was placed in a hole on a wall illuminated by the sun, vivid dragons and snakes, carts and horses could be seen on the wall inside a house.

ELECTRICITY AND MAGNETISM

Wang Chong recorded the shape, applications and direction indication of the ancient south pointing needle 'Si Nan'. Phenomena of magnetic attraction and repulsion were extensively noted. 'The repulsion by a magnet is very extreme'[18] is a description of repulsion. Wang Chong and Che Po (276 - 364) explained the attraction of static electricity and magnetism by using the doctrine of the essence of matter. Ancient folk had many imaginary applications of magnetism for anti-burglary, anti-sword, in combat and medicines. Even in 1660 when the book "On Magnetism" by W. Gilbert (1540 - 1603) was published, people in England still believed in the saying that magnets could be demagnetized by rubbing with garlic and could be remagnetized again by rubbing with goat blood. A similar belief by the Chinese was recorded as early as those in the books "Miscellaneous Techniques from Huai Nan" and "Huai Nan Zi".

In the Han dynasty, people discovered the static electricity attraction of amber and tortoise shell. Yu Fang in the State of Wu during the Three Kingdoms Period heard this saying when he was a child: 'Amber does not secure rotten vegetables and bendable needles will not be subject to a magnet'[19]. What that means is that rotten vegetables are not attracted by statically charged amber because of the conductivity in their moisture; and certain soft metals such as gold and copper are not attracted by magnets. Chang Hua noticed that a static charge was produced in combing hair and in undressing with silk and wool garments. He witnessed static sparks and the sound of discharging. Tao Hueng-Jin (452 - 536) discovered that the static attraction of amber was noticeably enhanced when rubbing it with cloth. Duan Cheng-Shi (dates of birth and death unknown) of the Tang dynasty noticed the static sparks when a hand stroked a cat.

SUNG, YUAN (960 - 1368)

The Sung and Yuan dynasties are the period when ancient Chinese physics prospered.

HEAT

In his "Summaries on Armament" Zung Gong-Liang (998 - 1078) documented the world's earliest prescriptions for powder. From the base of the invention of powder, various pwder weapons emerged. Rockets propelled by powder were invented as early as the 13th century, and were actually used in battles. When introduced to Europe, powder and rocket technology had a great impact on European societies and scientific technology.

Tao Ju living in the 19th century of the Sung dynasty first documented the method of making matches: 'When there was an emergency at night and a lamp was too slow to make, intelligent individuals would cut wood into sticks and dipped them in sulphur and have them ready for use. Flame would result as soon as the stick contacted fire, and this was miraculously constant. It was called 'light guiding slave'. Nowadays there is merchandise with a

different name, 'fire stick'.' Other names are 'candle' or 'little fire', with an even earlier date of invention. From stages of drilling for fire through striking metal to make fire, to making fire with a grained match (striking matches is an event of later days), heat technology is seen to progress.

People during the Sung dynasty even invented an oil economizing lamp. A small hole was drilled on one side of the lamp and pure cold water was poured into it to prevent heated oil from evaporating rapidly, hence reducing oil consumption by almost half.[20].

Tao Zong-Yi (living in the 14th century) at the end of the Yuan dynasty once performed an experiment on heated expansion and cooled reduction. He first heated an object with a hole or crack, then inserted another object into the hole or crack, making these two objects 'turn perfectly without the slightest gap'. He explicitly and correctly stated the fact that the former object 'fattened and expanded by boiling'[21].

Man discovered many materials in their natural state - lime stone, petroleum, oilpaper, maltose, horse dung and so on.

During the long practice of boiling water and making tea, people noticed the phenomenon of staged boiling of water. The stage prior to boiling, with the absence of air bubbles is called 'blinded eyes'; when water starts to boil, the bubbles resemble 'crab eyes', and then resemble 'fish eyes', and finally air bubbles jump and dance like pearls [22]. Using the above mentioned water with different temperatures to make tea would result in different effects - 'when water is not ripe the foam will be afloat, when water is overripe the tea leaf will sink'[23].

(To be continued)

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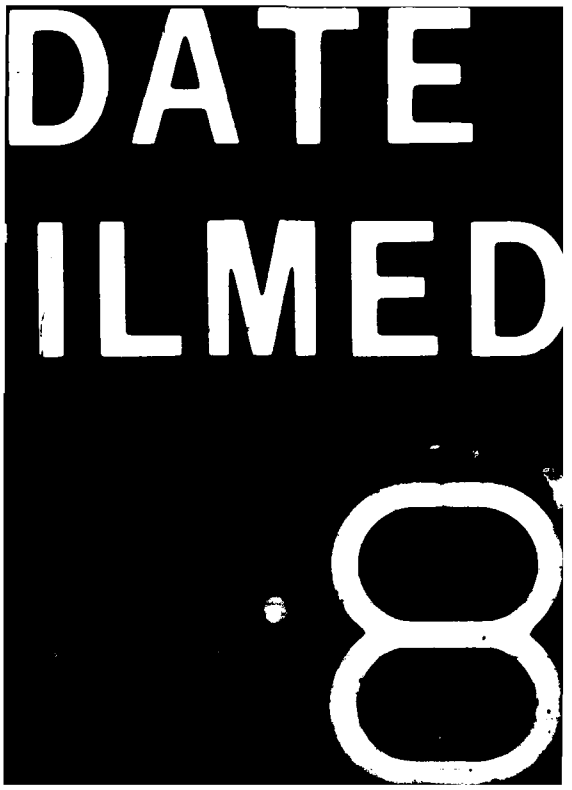
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